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Systems, Science and Software
P.O. Box 1620
La Jolla, California 92038

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Two tracer-gas pressurization studies were conducted in the Mighty Epic chimney. The objectives of these tests were to evaluate gas flow within the chimney and to measure the flow from the chimney through the surrounding material to the mesa or tunnel complex. The relative gas permeability and accessible gas-filled void volume of the chimney material was estimated from this data. This report describes the test procedures, test results, and chimney material properties as inferred from the test data.

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SUMMARY

During the Mighty Epic tracer gas chimney pressurization studies gas seepage from the chimney to the mesa, the Ming Blade chimney, the Misty North chimney and the tunnel complex was examined. Air containing a tracer gas was injected into the chimney. Gas samples were collected and analyzed for evidence of the injected tracer gas. The absence of tracer gas in all air samples collected on the mesa and in all air samples collected in the tunnel complex, the examined probe holes (with the exception of one hole drilled from the Mighty Epic interface re-entry drift), the Ming Blade and Misty North chimneys indicates there was no continuous gas seepage from the Mighty Epic chimney.

Chimney pressure histories and pressure arrival times were monitored and were used to estimate chimney material properties. The flow from the injection region to the upper portion of the chimney occurred as if the average relative gas permeability were about 4 darcies. This permeability is similar to that found in the Ming Blade chimney. The permeability in the lower region was initially significantly higher, but appeared to decrease as the pressurization test continued. This is thought to be a result of water flow in the lower chimney region. The chimney was found to have a relative gas porosity corresponding to a chimney air filled void volume of 1.9×10^5 cubic meters. This void volume is similar to that found in the Dining Car chimney.

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1. INTRODUCTION

Two tracer gas pressurization studies were conducted in the Mighty Epic chimney which is relatively close (i.e., approximately 5 cavity radii) to the Diablo Hawk working point (WP). These studies were carried out to aid in determining if the Mighty Epic chimney could satisfactorily contain any cavity gases which may possibly enter as a result of the Diablo Hawk event. A number of questions were addressed. First, do these gases percolate up through the chimney, diffuse through the paintbrush and caprock and finally leak into the atmosphere above the mesa? Second, do chimney pressures become large or can the gas easily diffuse throughout the chimney so that it acts as a dump volume to contain the cavity gases? Finally, is the Mighty Epic chimney sufficiently isolated so that gas entering the chimney will not seep into the tunnel complex? The intent of these studies was to determine the properties of the Mighty Epic chimney and its surroundings in the hope these questions may be answered.

A number of specific objectives were addressed during these tests. Most importantly, the ability of gas to seep from the Mighty Epic chimney to the mesa was examined. Gas seepage from the chimney into the tunnel complex was also investigated. In addition, relative gas permeabilities and porosities of the chimney material were estimated and compared to results obtained through investigations of the Ming Blade and Dining Car chimneys.

The first and second Mighty Epic tests initiated on 12 November 1976 and 4 March 1977 respectively, proceeded as follows. Air plus a tracer gas was injected into the chimney from the tunnel complex. Pressures and tracer gas arrival times were then measured at various points within the chimney.

These data were used to estimate chimney properties such as relative gas porosity and permeability. Air samples were also collected at various locations on the mesa and in the tunnel complex. These were examined for evidence of tracer gas in order to provide a direct measure of the communication between the chimney and either the mesa or tunnel complex. Gas samples were analyzed using the Systems, Science and Software (S^3) chromatograph.

Results of the Mighty Epic chimney pressurization studies indicate this chimney is a competent containment vessel. There was no evidence of gas seepage from the chimney to the mesa. Seepage to the tunnel complex only occurred for a very short time period in the vicinity of a probe hole driven from the Mighty Epic interface re-entry drift. The relative gas permeability and porosity of the chimney material was found similar to that of the material in the Ming Blade chimney. Its accessible air-filled void volume was found to be approximately twice the original cavity volume. This is similar to the volume available within the Dining Car chimney. Some anomalous results were obtained during the first Mighty Epic test. These are discussed in detail in the report.

In the report which follows, a brief description of the Mighty Epic chimney geometry and the surrounding geology will first be given. Section 3 will include a complete description of the test procedures, instrumentation and measurement techniques. Experimental results for all tests conducted on the Mighty Epic chimney will be presented in Section 4. Included in this section are results of tests carried out to determine communication between the chimney and either the mesa or tunnel complex. Analytical-numerical techniques used to estimate chimney properties such as accessible air-filled void volume and relative gas permeability are presented in Section 5. A complete description of the inferred material properties is given there. A summary of all results is given in the final section.

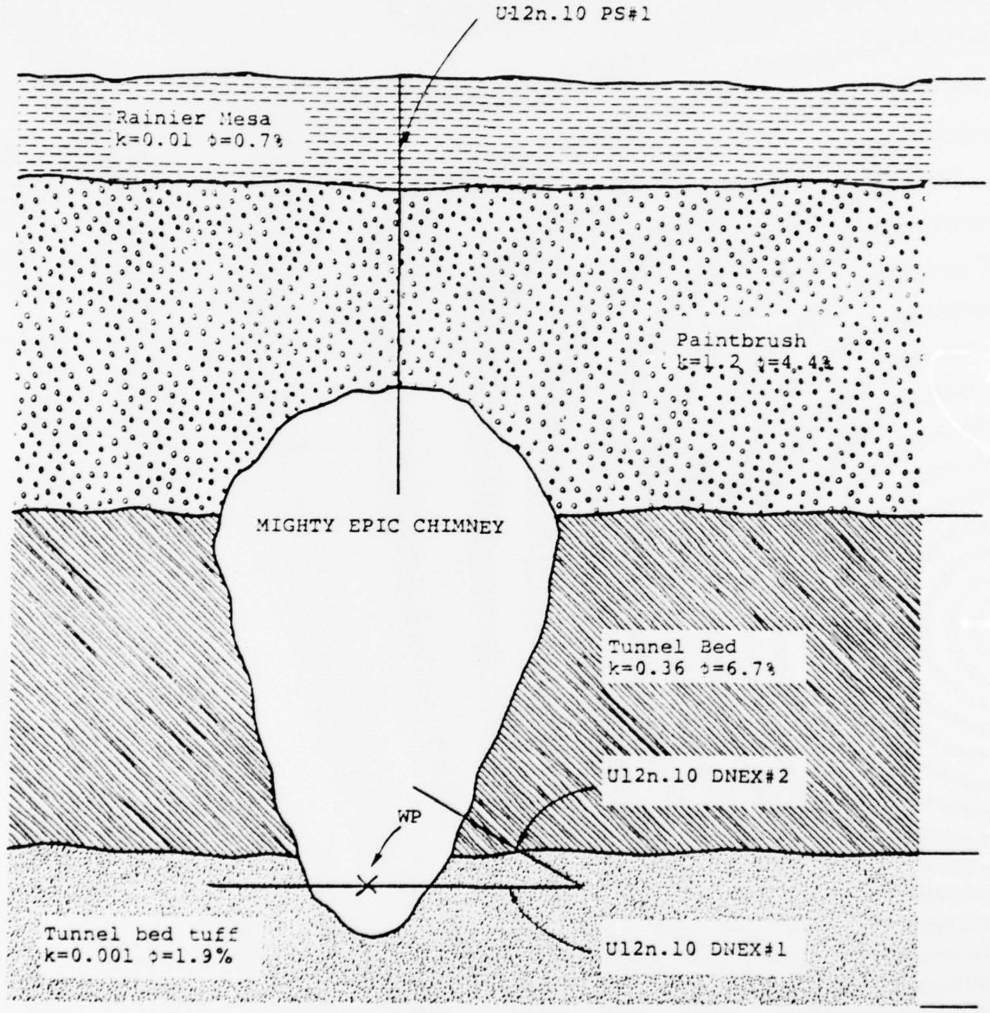
These tests were carried out under the direction of Joe LaComb of DNA. Systems, Science and Software (S^3) served as a consultant. In addition, S^3 was responsible for the performance of the tracer gas studies and for the interpretation of the pressure and tracer gas results to estimate properties of the chimney material. The following report summarizes the S^3 activities and results in considerable detail. To make this summary meaningful, it is, however, necessary to include some background information concerning the test itself. A minimum amount of information is therefore included on the geology, chimney geometry, test equipment, test procedures and test results. It is anticipated that DNA will provide a more complete report covering these subjects.

2. DESCRIPTION OF MIGHTY EPIC CHIMNEY AND SURROUNDINGS

The Mighty Epic chimney and surrounding strata are shown in Figure 1. An estimate of the chimney geometry was made from drill-back information. The working point (WP) location is known, and positions at which the three drill holes intersect the chimney can be estimated from drilling information. The remainder of the chimney geometry is then extrapolated from these four known positions. Properties of the chimney material are unknown. Some approximate properties for the surrounding strata are shown in Figure 1. These material property values are given here to illustrate the differences between the various layers.

Material property data shown in Figure 1 were taken from Reference 1. They represent Terra Tek data taken from competent samples obtained from the UE12n. #9 exploratory hole. Values of permeability were determined from oven dried samples and consequently are likely to greatly overestimate the gas permeability of competent in-situ material. Gas permeability data are also shown in Reference 1 for saturated tuff. There is a gross discrepancy between dry and saturated tuff permeability with values differing by about two orders of magnitude. However, the presence of fractures in the in situ material may greatly increase the effective permeability of the formation. Preliminary testing, based on the Dining Car U-12e.18 PS#1 hole indicates this to be the case. In fact, whole hole permeability tests conducted on this hole indicate the relative gas permeability of the paintbrush material may, indeed, be very similar to the permeability of the oven dried competent material.

Interpretation of the test data is, in many cases, sensitive to the condition of the drill hole. Therefore, a



k = relative gas permeability (darcy)
ϕ = relative gas porosity (percent)

Figure 1. Mighty Epic chimney geometry and surrounding geology.

detailed description of these holes will be given. The three drill holes are shown in relation to the chimney geometry in Figure 2.

U-12n.10 PS#1 is a vertical hole beginning at the surface ground zero (SGZ) on the mesa. During both tests this 10 cm diameter hole was uncased except for a 27.4 m collar leading from the mesa surface into the caprock. This 166 m hole terminated in the top of the chimney. A 0.024 cm diameter copper capillary tube had been placed in this hole in order to draw gas samples from the top of the chimney. Unfortunately this hole was blocked during the first test.

The U12n.10 DNEX#2 hole began in the U12n.10 bypass drift and continued into the chimney at an angle of 26^{o} from the horizontal. This hole was drilled to a depth of 57 m. The first 53 meters were cased and grouted using 7.8 cm diameter HQ rod. The remaining 4 meters of this 10 cm diameter drill hole were left uncased and served as the source for air injection into the chimney. A 1.27 cm diameter copper tube, used for downhole pressure measurements, had been inserted to a depth of 53 meters.

The U12n.10 DNEX#1 hole extended into the chimney to the working point. A 7.8 cm diameter HQ casing, sealed to the collar at a depth of 9 m, extended to a depth of 65 m. A 0.024 cm diameter capillary tube had been placed in this hole to a depth of 65 m in order to obtain gas samples from the region of the WP.

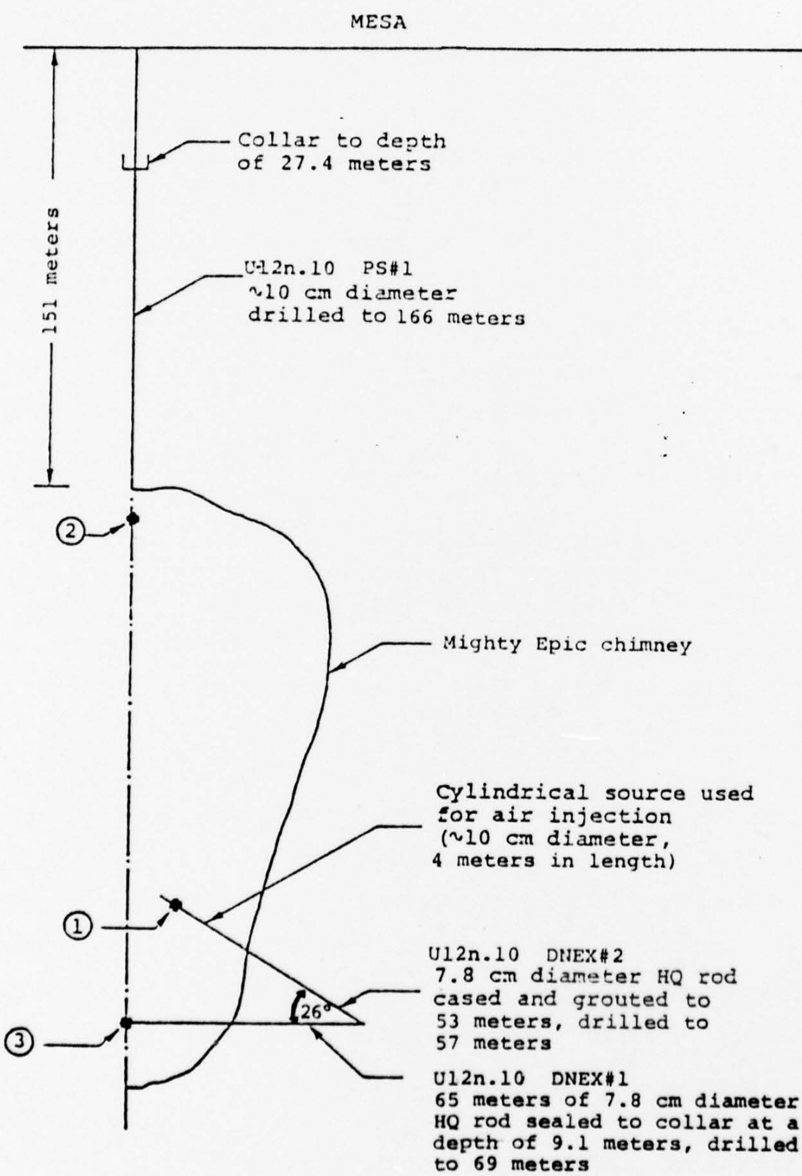


Figure 2. Mighty Epic chimney showing a detailed description of all drill holes.

3. TEST DESCRIPTION

The tracer gas chimney pressurization tests proceeded as follows. Air containing a tracer gas was injected into the U12n.10 DNEX#2 hole for a specified number of hours. Pressures at the source, working point and chimney top were monitored during both the pressure rise and decay periods. Gas samples were periodically collected from the working point and chimney top and subsequently analyzed to determine tracer gas arrival times. These data were then used to estimate the accessible air-filled void volume and relative gas permeability. In addition, air samples collected at points on the mesa and in the tunnel complex were analyzed for evidence of tracer gas in order to determine if gas was seeping from the chimney.

3.1 PRESSURE MEASUREMENTS

Pressure measurements were made within the chimney at points 1, 2 and 3 shown in Figure 2. Unfortunately, the U-12n.10 PS#1 hole was blocked throughout the first test, thus pressure data was not obtained at point 2 during that test. However, during the first test pressure data was obtained from the U12n.10 DNRE#2 hole shown in Figure 3. During the second test pressure data was obtained at the various probe holes drilled from the interface re-entry drift shown in Figure 4, the Ming Blade and Misty North chimneys, and from a probe hole near the Diablo Hawk WP. The detailed positions and depths of these probe holes are available from DNA. Measurements were made using water manometers, mercury manometers or gauges as the situation dictated. Sensitive readings were obtained using water manometers capable of measuring pressures ranging from 0.07 to 20 KPa. Recording microbarographs were located on the mesa and in the tunnel in order to provide a record of atmospheric pressure changes. Manometer data were corrected for these changes as required. All pressure data were recorded by H & N personnel throughout these tests.

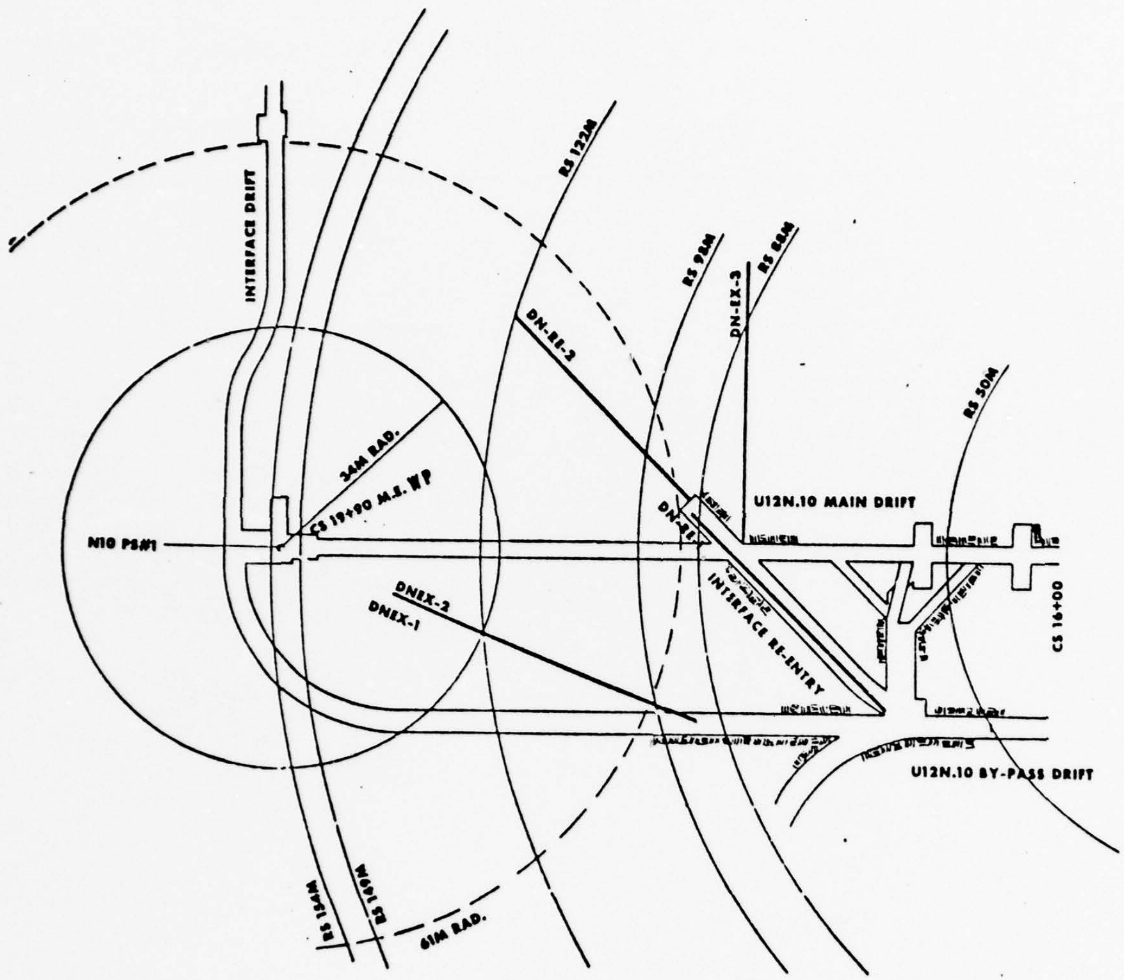


Figure 3. Schematic showing the location of the U12n.10 DNRE#2 probe hole used for tracer gas and pressure measurements.

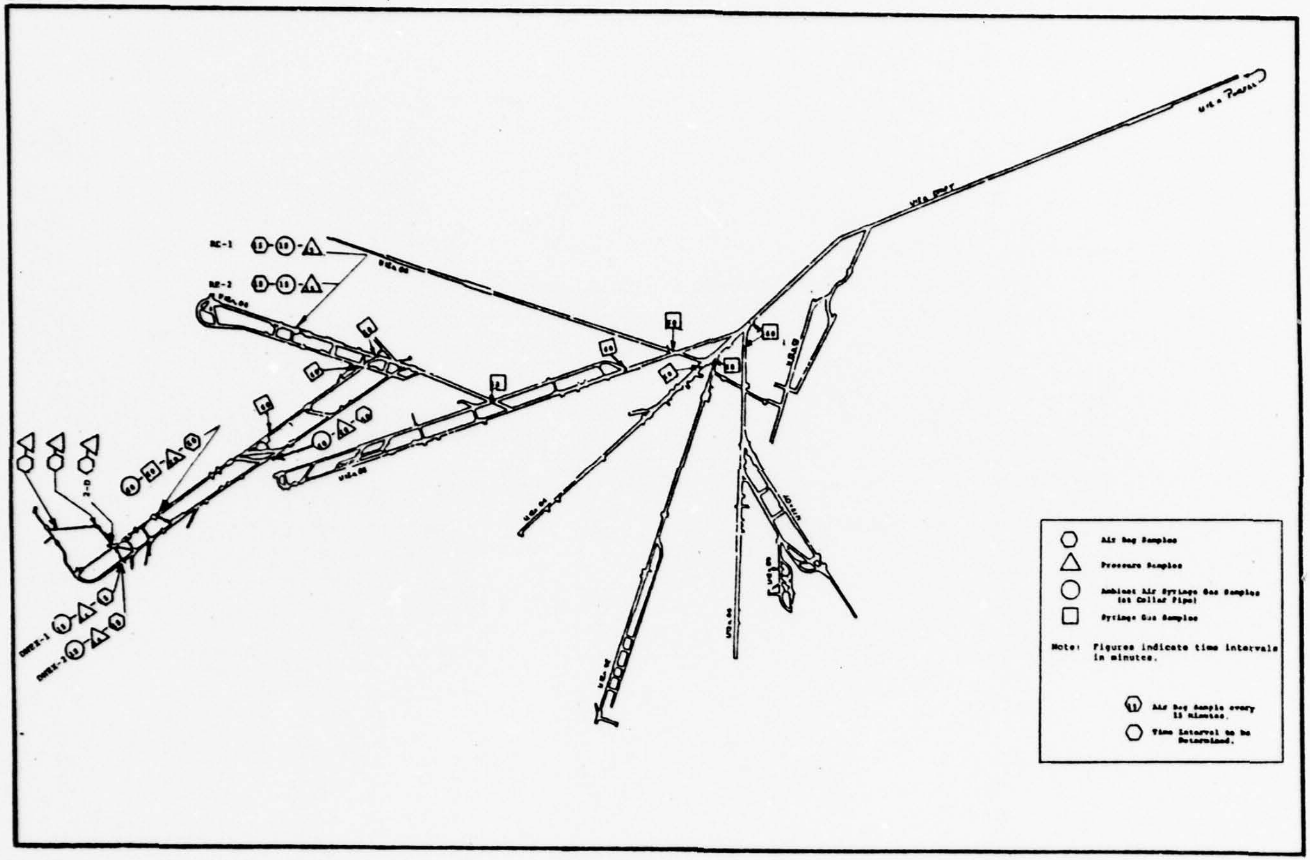


Figure 4. Schematic showing the locations for pressure and tracer gas sampling during the 4 March 1977 Mighty Epic chimney pressurization test.

3.2 FLOW RATE MEASUREMENTS

A schematic of the injection apparatus used for the second test is shown in Figure 5. Air, used as the carrier gas, was piped from the portal to the injection site through a 15.2 cm diameter line. This line was reduced to two 5 cm diameter lines prior to reaching the injection manifold. The Halliburton 5 cm diameter LO-II flow meter was placed in one of these smaller lines. When possible, flow rates were measured using this meter. Flow rates were also calculated[2] based on the pressure drop along the injection hole. When the flow meter was working properly, the calculated and measured rates agreed to within 10 percent.

The tracer gas was injected into the main airstream using the manifold shown in Figure 5. Almost all joints in this manifold were welded to prevent leakage of the tracer gas into the tunnel complex. Unfortunately, a few threaded joints existed. These go from the manifold to the valves connected to the manometer lines and to the line leading to the tracer gas source. In the first test, Freon C318 was used as a tracer gas. The gas bottle was placed on a beam scale and mass flow rates were determined from measurements of the bottle weight as a function of time. Freon 114 was used as the tracer in the second test. At the working pressures this tracer appears in the liquid form. To facilitate the use of Freon 114, it was maintained in the gaseous state by dilution (1 part per 100) in N_2 so that its partial pressure always remained less than the saturation pressure at which condensation occurs. The Freon 114-N_2 mixture was stored at 13.1 MPa in 60 T size cylinders. These cylinders were connected using a common manifold and the mass flow rate of tracer gas was calculated from measurements of the time variation in system pressure.

3.3 TRACER GAS MEASUREMENTS

Gas samples were collected at prescribed intervals on the mesa, in the chimney, at various probe holes, and within the

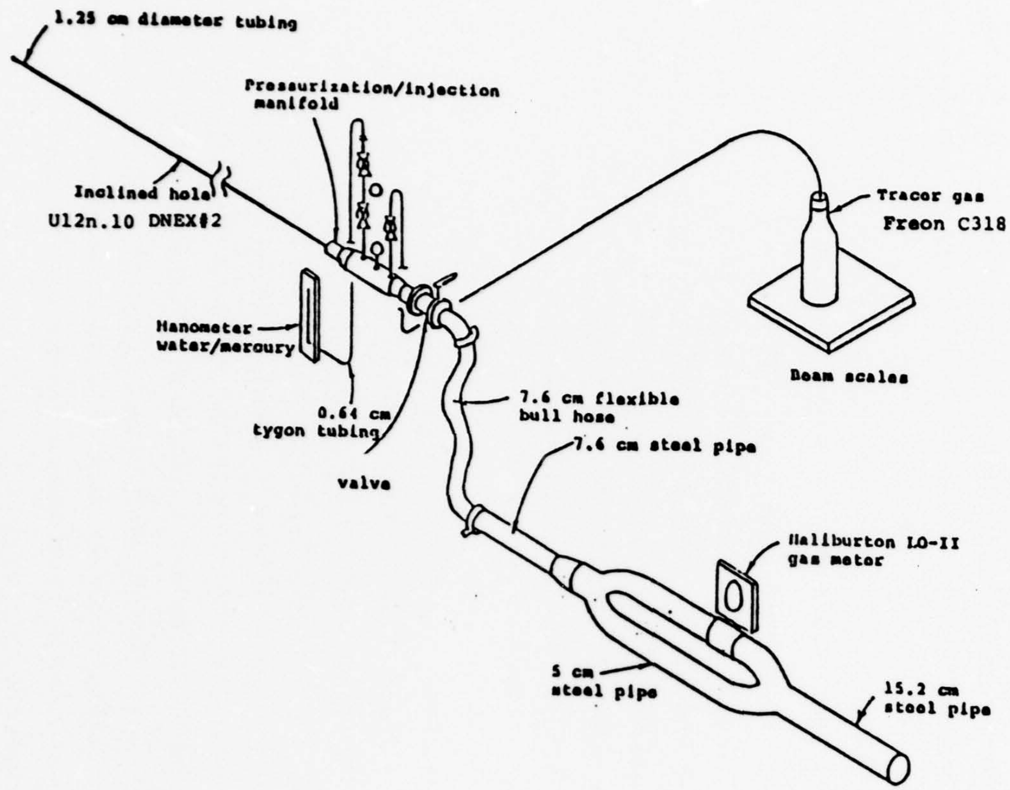


Figure 5. Schematic showing injection apparatus.

tunnel complex. These samples were returned to the instrumentation station located at the Mighty Epic surface ground zero (SGZ) or to one of the two stations located in the U12n.10 tunnel complex where they were analyzed for evidence of tracer gases.

Mesa samples were taken at points shown on the grid in Figure 6. This grid was 305 m in diameter centered on the Mighty Epic SGZ. Sampling locations were at the 61 m, 152 m, and 305 m positions on each of 12 radials oriented at 30° intervals and at the SGZ. In practice, one man carried sufficient syringes in a small basket-like container to allow him to walk two radials; one out, and then a second radial on his return to the SGZ area. At each location, replicate samples (i.e., two samples) were drawn by first aspirating the syringe and then drawing a sample approximately 1 cm above the ground. When all six sample locations had been occupied, the full basket was returned to the instrumentation station for analysis. At all times during which samples were drawn on the mesa, a Meteorology Research, Inc. portable weather station was in operation. This weather station measured wind speed and direction as well as outdoor temperature. In this way it is possible to correlate observed tracer gas patterns with prevailing winds and thereby make inferences about the total amount of tracer gas observed and also to assess the possibility that any observed tracer gas was a spurious leak contributed by a tunnel portal rather than an actual leak to the surface of the mesa.

Gas samples were scheduled to be taken from within the chimney at points ② and ③ (see Figure 2) and at the U12n.10 DNRE#2 probe hole during the first test. Unfortunately the U-12n.10 PS#1 hole was blocked, thus preventing acquisition of samples from point ②. During this test the chimney pressure response did not behave as anticipated, and as a result some gas samples were taken within the tunnel complex to try and

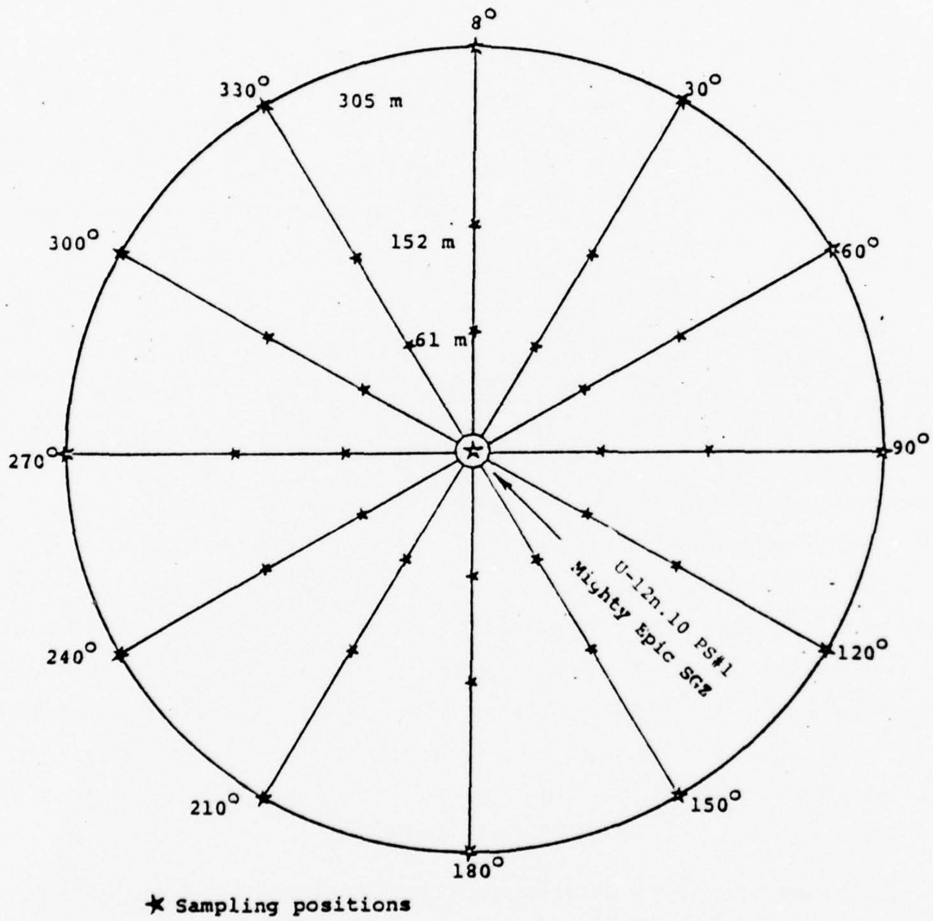


Figure 6. Mesa sampling grid centered on the Mighty Epic SGZ.

determine if there was significant seepage of gas from the chimney. During the second test tracer gas samples were taken from the Mighty Epic, Ming Blade and Misty North chimneys, and the probe holes and positions within the tunnel complex shown in Figure 4. In order to prevent mixing of air within the tunnel complex, which may lead to spurious indications of tracer gas, the tunnel ventilation system was turned off and train traffic was halted for the duration of the test.

Details of the sampling and measuring techniques are given in Reference 2. Air samples were analyzed for evidence of tracer gas using the Systems, Science and Software (S^3) electron capture gas chromatograph. The ultimate sensitivity of the S^3 tracer gas monitor to the Freons C318 and 114 used in these tests is approximately 10^{-10} and approximately 10^{-9} parts tracer per part air, respectively.

4. EXPERIMENTAL TEST RESULTS

Two tracer gas pressurization tests were conducted in the Mighty Epic chimney. The first of these tests began on 12 November 1976. The objective of that test was to evaluate the properties of the Mighty Epic chimney and surrounding materials and to evaluate the possibility of gas seepage from the chimney to the mesa. During this test the U-12n.10 PS#1 hole was blocked (i.e., a packer had failed to release), thus pressure and tracer gas arrival data could not be obtained at the top of the chimney. There were implications of gas seepage from the chimney into the tunnel complex during this test. Consequently, a second test was initiated on 4 March 1977. The intent of this test was to evaluate seepage from the chimney to the tunnel complex and to obtain pressure arrival data at the top of the chimney so that the relative gas permeability and porosity of the chimney material could be estimated. The U-12n.10 PS#1 hole was open at the time of the second test. Results of these tests are discussed in the following sections.

4.1 12 NOVEMBER 1976 TEST

During this test pressure data was obtained in the chimney at points 1 and 3, shown in Figure 2, and from the interface re-entry drift probe hole shown in Figure 3. Tracer gas arrival data were obtained at the later two positions. Gas seepage from the chimney to the mesa was evaluated by analyzing mesa air samples collected at points shown in Figure 6 for evidence of Freon C318.

Pressurization began at 1815 on 12 November 1976 through the U12n.10 DNEX#2 hole and continued until 1500 on 13 November 1976. During this time approximately 5.6 x 10^4 standard cubic meters (SCM) of air were injected into the chimney. Freon C318 was injected as the tracer at a concentration of 3 x 10^{-5} parts tracer per part air during the first 15 hours of pressurization. This tracer gas was detected at the WP and the interface re-entry drift probe hole beginning approximately one hour after its injection into the chimney through the U12n.10 DNEX#2 hole. The resulting chimney and probe hole pressure histories are shown in Figure 7.

Air samples were collected on the mesa at the position shown in Figure 6. These samples were taken at 0800, 0900, 1000, 1100, 1200, 1300, 1400 and 1500 hours on 13 November 1976. No evidence of Freon C318 was found in any of these samples. During the 12 November 1976 test, there was no indication of gas seepage from the chimney to the mesa.

The sequence of events occurring during the first Mighty Epic chimney pressurization test requires further explanation. At the time the test was initiated, it was thought that the U-12n.10 PS#1 hole from the mesa to the chimney was open. During the first 2 hours of air injection the pressure histories at points 1 and 3 within the chimney behaved in the usual fashion observed in previous tests.[2,3] Pressure arrival had as yet not been observed at the top of the chimney, however, this was not considered unusual. At the two hour mark, shown in Figure 7, the rate of pressure increase at point 3 decreased drastically, while the probe hole pressure began to rapidly increase. This behavior continued for a number of hours, yet there was no indication of pressure arrival at the chimney top. Based on this minimal information, concern was expressed that the air injected into the chimney was going elsewhere. Consequently, gas samples were collected at various locations within the tunnel complex and analyzed for Freon C318 in order to determine if air was seeping back into the tunnel complex from the chimney. Results of this survey are given in Appendix I. Significant quantities of this tracer gas were found at the Mighty

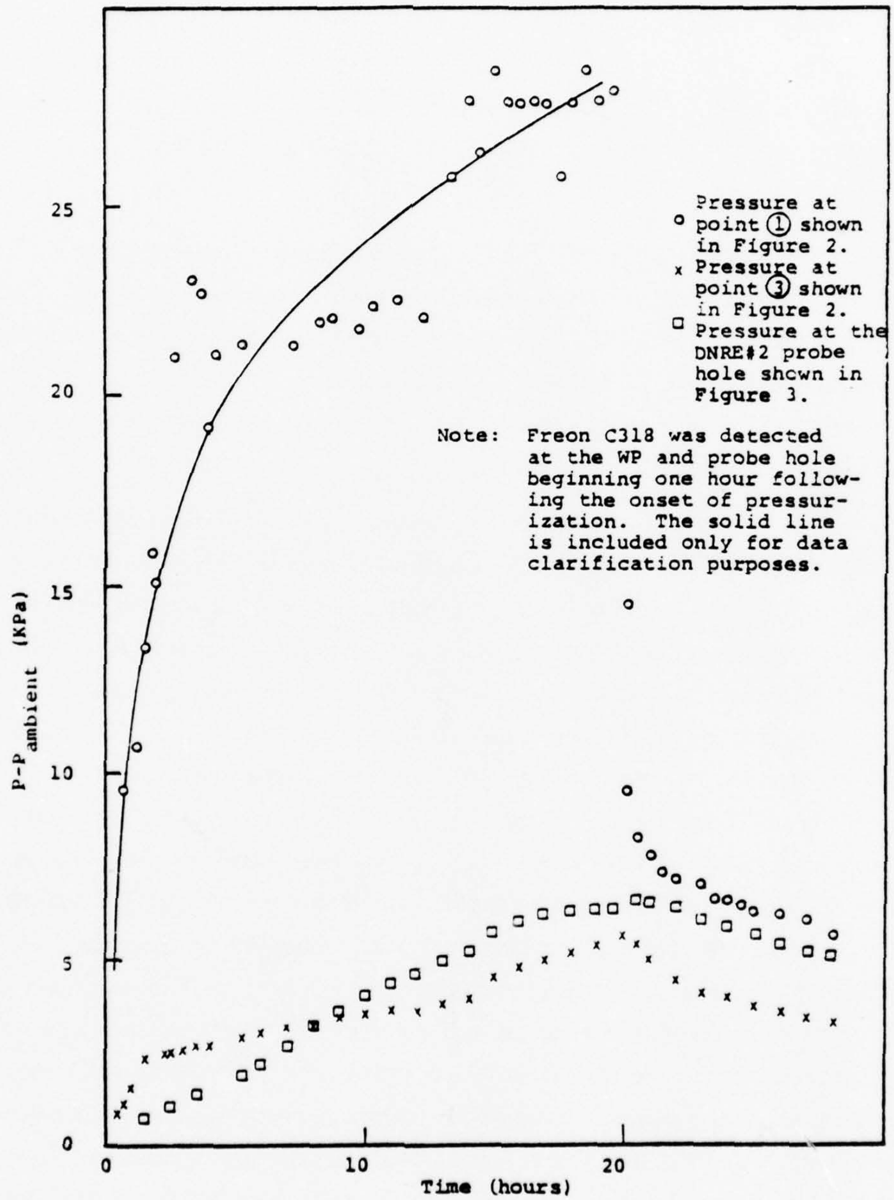


Figure 7. Measured Mighty Epic chimney pressure history during the 12 November 1976 tracer-gas pressurization test.

Epic working point, as might be expected, and in the interface re-entry drift probe hole. The Freon C318 background level, measured at the S^3 instrumentation station located at the intersection of the Mighty Epic bypass and interface re-entry drifts remained negligible throughout the duration of the test. However, significant quantities of Freon C318 were found in the vicinity of the Ming Blade drift, the Diablo Hawk working point and the Mighty Epic DAC. In addition, there existed easily measurable concentrations of SF_6 and Freon 13B1 (injected into the Ming Blade chimney during July of 1976) at these latter positions.

By approximately 1000 hours on 13 November 1976 it had been determined that the U-12n.10 PS#1 hole was blocked, thus accounting for the failure to obtain a pressure arrival at the top of the chimney. Injected air may therefore have been flowing to the upper portion of the Mighty Epic chimney in which case the pressure rise at the WP may be small. It was also determined at about this time that the U12n.08 RE#1 hole into the Ming Blade chimney was not capped. This may provide a ready explanation for the SF_6 and Freon 13B1 found in the tunnel complex since the chimney will breathe as a result of changes in atmospheric pressure.

Many hypotheses have been put forward to explain the observed presence of Freon C318 in the tunnel complex. However, none can be substantiated. The lack of significant quantities of this tracer at the injection region around the U12n.10 DNEX#2 hole and at the S^3 instrumentation station does however strongly support the argument that this gas did not enter the tunnel complex as a result of leakage around the injection manifold. By 1000 hours on 14 November 1976 measurable quantities of SF_6 and the Freons 13B1 and C318 were found throughout the N tunnel complex. Since the tunnel ventilation system pulls air from the portal toward the working face, the dispersion of tracer gas throughout the complex has been attributed to air mixing resulting from the train movement (see Appendix I).

4.2 4 MARCH 1977 TEST

This test was performed to evaluate the possibility of gas leakage from the Mighty Epic chimney into the tunnel complex, and to obtain pressure arrivals at the top of the chimney. At the time of this second test, the U-12n.10 PS#1 hole was open to the top portion of the chimney. This test was intended to be of short duration, thus the tracer gas was not expected to travel to the top of the chimney or to the mesa. As a result, air samples were not collected on the mesa. However, a complete tunnel survey was performed. Pressure and tracer gas samples were obtained from the probe holes drilled from the interface re-entry drift, a probe hole near the Diablo Hawk WP, and the Mighty Epic, Ming Blade and Misty North chimneys. In addition, tracer gas samples were obtained at the positions in the tunnel complex shown in Figure 4. Throughout this test the tunnel ventilation system was off, and all train traffic had been halted in order to limit air currents in the tunnel complex.

Pressurization began at 1134 on 4 March 1977 through the U12n.10 DNEX #2 hole and continued until 1752 hours. During this time approximately 2.4×10^4 SCM of air containing Freon 114 at a concentration of 2×10^{-4} parts tracer per part air were injected into the chimney. The resulting chimney and probe hole pressure histories are shown in Figure 8. A trace of Freon 114 was detected in a sample taken from the WP at 1517 on 4 March. All other samples taken at the WP were free of this tracer.

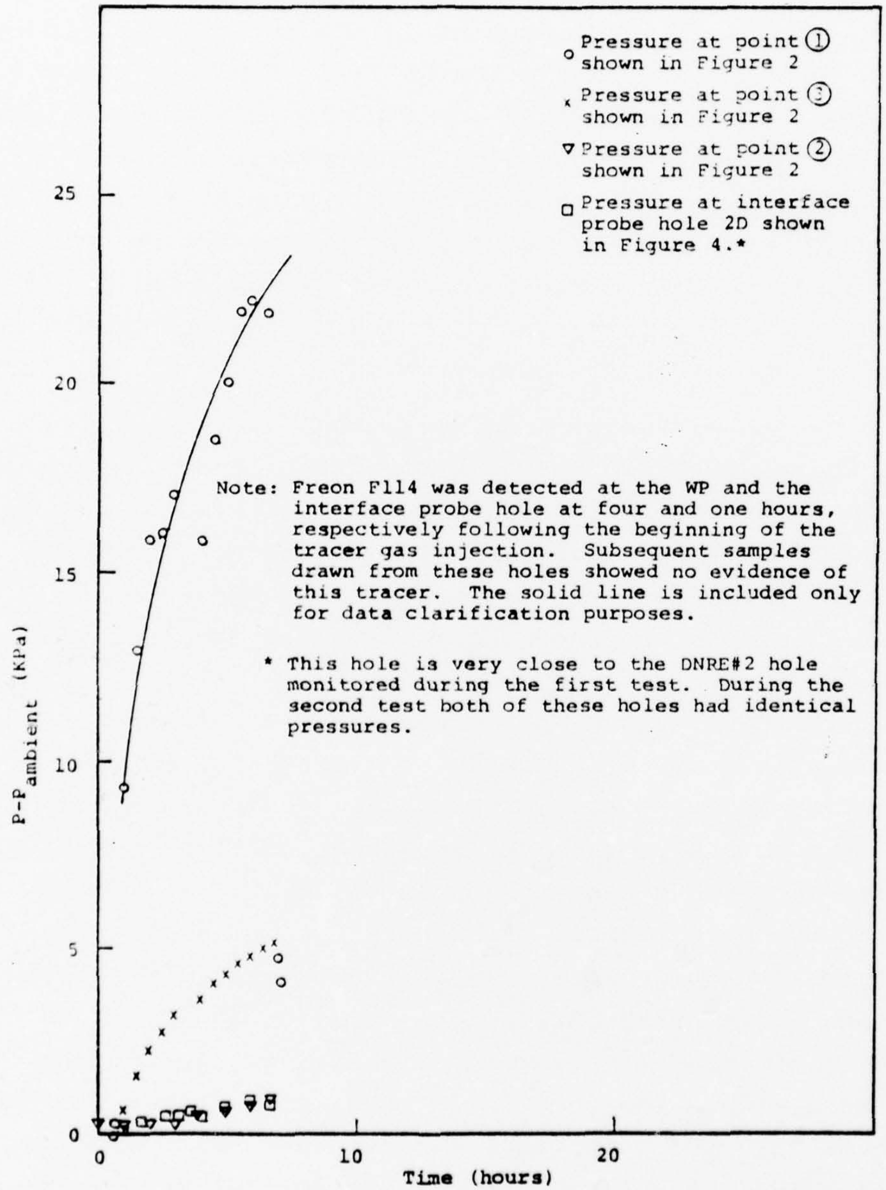


Figure 8. Measured Mighty Epic chimney pressure history during the 4 March 1977 tracer-gas pressurization test.

Air samples were collected at the probe holes drilled from the interface re-entry drift, a probe hole near the Diablo Hawk WP, and the Ming Blade and Misty North chimneys. Gas samples were also collected at the various tunnel stations indicated in Figure 4. Freon 114 was detected in the interface re-entry drift probe hole located at station CS 1+72 shown on Figure 4, and in the interface re-entry drift adjacent to this hole at approximately 1300 hours on 4 March (i.e., approximately 1 hour following tracer gas injection). Subsequent air samples taken at these locations were free of the tracer. There was no evidence of tracer gas at any other stations. During the 4 March 1977 test, there was no indication of significant gas seepage from the Mighty Epic chimney into the tunnel complex.

Prior to the onset of pressurization, gas samples were drawn from the Mighty Epic and Ming Blade chimneys. Air samples taken from Ming Blade showed significant quantities of SF_6 and Freon 13B1. Both of these gases had been injected into this chimney during previous tests. Air samples taken from the Mighty Epic chimney showed evidence of SF_6 and the Freons C318 and 13B1. Only Freon C318 had been previously injected into the Mighty Epic chimney. There are numbers of possible mechanisms by which the other tracers reached the Mighty Epic chimney. The Ming Blade pressurization tests occurred in July 1976, thus many months had passed and possibly gas flow from the Ming Blade to the Mighty Epic chimney occurred through the paintbrush. Alternatively, these tracer gases may have entered the Mighty Epic chimney through the air pressurization system. Common parts of this system were used for both the Ming Blade and Mighty Epic tests. In addition, if the main tunnel compressed air system had been left open to the chimney, there exists the possibility that some tracer-ladened air had moved into the compressed air line and was subsequently injected into the Mighty Epic chimney during preliminary pressure tests. The absence of Freon C318 in the Ming Blade chimney is thought to be quite significant and indicates there is no flow path from Mighty Epic through the surrounding formation into the Ming Blade Chimney.

The difference in pressure response during the Mighty Epic tests is easily distinguished in Figures 7 and 8. Again, a number of hypotheses have been put forward to explain these differences, none of which can be completely substantiated. The most easily accepted hypothesis is that of different rates of water migration toward the lower portion of the chimney during the two tests. The scatter in pressure data taken from the U12n.10 DNEX#2 hole resulted because the pressure line was continually filling with water. This line was drained at intervals, and these drainages account for the seemingly step increases in pressure. The data obtained during the second test appears smoother, thereby indicating less water motion, however, the data may be smoother because the line was drained at shorter time intervals. Interpretation of the pressure data will be discussed in more detail in Section V.

5. DETERMINATION OF MATERIAL PROPERTIES

The tracer gas pressurization technique may be used to evaluate certain properties of the chimney material and its surroundings. Quantitative evaluation of the relative gas permeability and porosity distributions can be determined using methods outlined in the Ming Blade and Dining Car[2] studies. Permeabilities and porosities, as used in this context, are defined as those required to explain the observed gas flow within the chimney assuming water contained in the material is immobile. Because of the paucity of Mighty Epic chimney pressure data these properties cannot be determined to the extent obtained in previous studies.[2,3] However, an average value for the relative gas permeability and the total air filled void volume within the chimney have been estimated using measured flow rates, pressure arrivals and pressure histories. These are compared to similar estimates made for the Dining Car and Ming Blade chimneys. In addition, a limited number of analyses were carried out to obtain some understanding of the possible phenomena responsible for the observed differences in the chimney pressure histories during the two Mighty Epic tests. These results are also presented in the following paragraphs.

A summary of the tracer gas chimney pressurization studies carried out on the Ming Blade, Mighty Epic and Dining Car chimneys is shown in Table 1. The average relative gas permeability of the material lying between the injection hole and the top of these chimneys was found to be 8, 4, and 150 darcies, respectively. These values were determined based on the pressure arrival time at the top of the chimney. An accessible air filled void volume of 2.2×10^5, 6.8×10^5, and 3.4×10^5 was found for the Mighty Epic, Ming Blade and Dining Car chimneys,

Table 1. Summary of Tracer Gas Chimney Pressurization Studies

Date Tested	Chimney	Estimated chimney volume (drill back information) (m^3)	Accessible Air-filled void volume** (pressurization study) (m^3)	Void fraction	Average relative gas permeability (darcy)	Average permeability of surrounding media (darcy)	Volume of air injected into chimney (SCM)	Time to pressure arrival at top of chimney (hr)	Time to tracer arrival at top of chimney (hr)	Time to tracer arrival on mesa (hr)	Tracer gas	Sensitivity threshold (concentration of tracer)
7/6/76	Ming Blade	--	--	-	-	-	2.8×10^4	No vertical hole		No tracer on mesa	SF_6	10^{-12}
9/24/76	Ming Blade	7.1×10^6	6.8×10^5	.10	8	1	5.7×10^4	5	56 (13*)	No tracer on mesa	Freon 13B1 (CF_3Br)	10^{-11}
11/12/76	Mighty Epic	2.3×10^6	2.2×10^5	.10	-	-	5.7×10^4	Vertical hole blocked		No tracer on mesa	Freon C318 (C_4F_8)	10^{-10}
1/24/77	Dining Car	2.0×10^6	3.4×10^5	.17	150	1	11.3×10^4	0.5	6	24-39 (Concentration 10^{-10}-10^{-11})	Freon 13B1 (CF_3Br)	10^{-11}
3/4/77	Mighty Epic		1.9×10^5	.09		1	2.0×10^4	3				

*The SF_6 which was injected during the 7/6/76 test was detected at the vertical hole 13 hours after the initiation of the 7/24/76 test.

**Based on pressure rise after two hours of air injection. The two hour period was selected so comparisons could be made with the short duration second Mighty Epic test. Air void volumes calculated based on the pressure increase at later times will be larger. Calculations indicate accessible air-filled void volumes of 6.8×10^5 m^3 and 4.1×10^5 m^3 for Mighty Epic (first test, pressure increase after 20 hours) and Ming Blade (pressure increase after 10 hours) respectively.

respectively. These volumes are based on the chimney pressure increase observed after 2 hours of air injection. Using these very crude (i.e., void volumes are accurate to within approximately 30%) methods for data interpretation, it can be seen that the permeability of the Mighty Epic and Ming Blade chimney materials are essentially the same. Furthermore, the total chimney volume, relative gas porosity, and accessible air filled void volume of the Mighty Epic and Dining Car chimneys are similar. The average relative gas permeability and relative gas porosity of the Mighty Epic chimney material is therefore similar to that observed on previous tests.[2,3]

A number of calculations were performed to determine a distribution of the relative gas permeabilities and porosities which would yield compatible calculated and measured pressure histories. Two satisfactory material property distributions were obtained for the second Mighty Epic test. However, even for that test, the pressure history at the working point can not be matched without assuming there is either a flow channel leading from the chimney or there exists a layer between the injection region and working point where significant water migration takes place. Figure 9 shows the pressure history obtained using the set of material properties defined in Figure 10. In this case, a layer 12 meters thick, having a relative gas permeability which decreases rapidly with increasing pressure, was placed between the injection region and the WP. Physical properties of this layer are meaningless. The layer was introduced in an attempt to qualitatively model the effects of water migration toward the lower chimney region. Under such conditions, the available pore space becomes plugged with the less mobile water with the result of greatly reducing the gas flow. If the permeability in the lower chimney region is assumed constant, the pressure curve at the working point continues to increase at a slope close to that occurring during the first

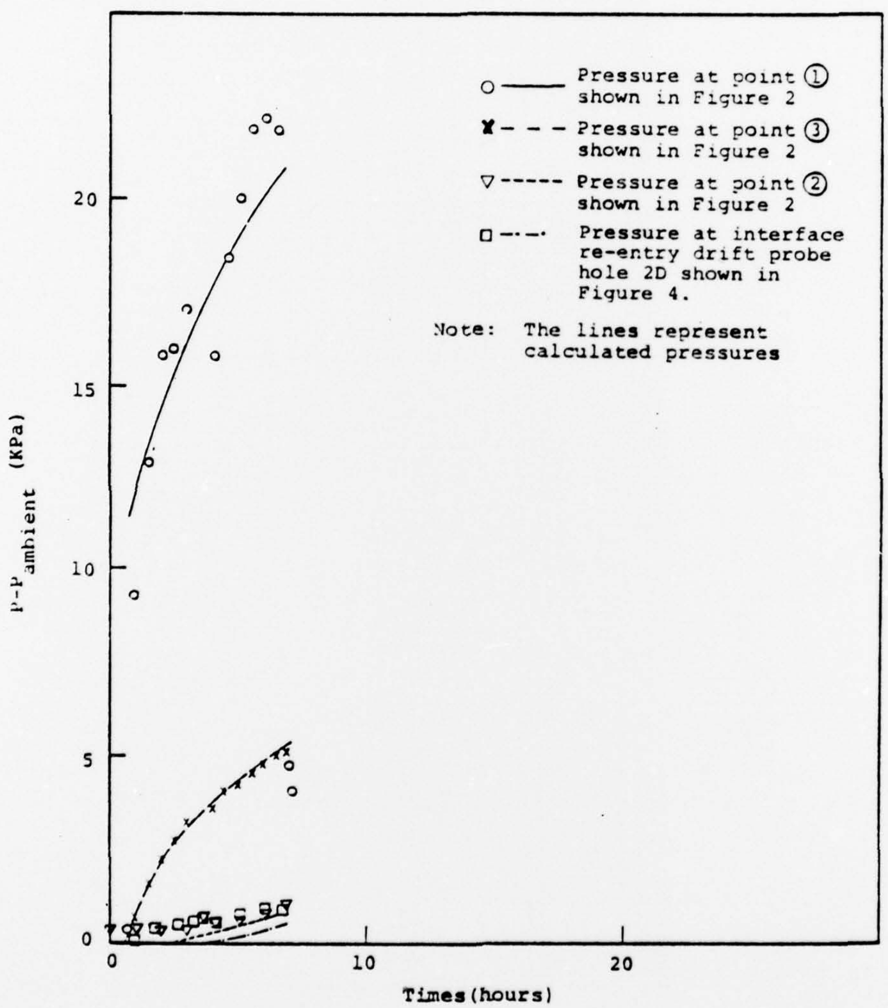


Figure 9. Comparison of measured pressures with calculated values obtained using values of relative gas porosity and permeability shown in Figure 10.

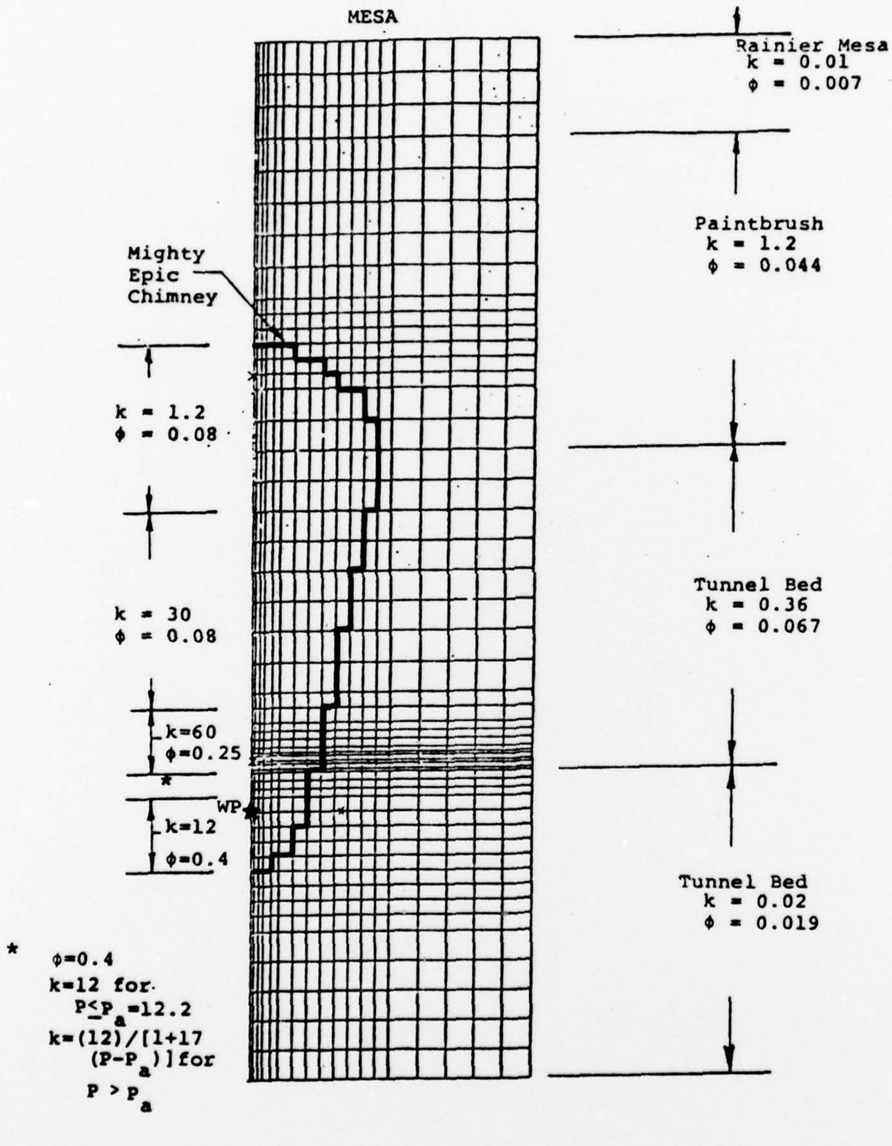


Figure 10. Calculational grid for Mighty Epic chimney showing distribution of material properties used to obtain the results shown in Figure 9.

two hours of pressurization. As a result, after a few hours, the calculated chimney pressures are always larger than those measured. An alternative solution shown in Figure 11 was obtained assuming there existed a flow channel leading from the lower chimney region as shown in Figure 12. Again, measured pressure histories can be reproduced using this model. It should be noted in both Figures 9 and 11 that the calculated pressures at the top of the chimney are lower than those measured. However, there existed a residual pressure at the chimney top at the beginning of these tests and if the residual is subtracted the measured and calculated pressure histories are in close agreement.

A number of attempts have been made to calculate the pressure response observed during the first Mighty Epic test. Both the flow channel model and variable permeability layer model have been used in these attempts. The closest reproduction of the measured data has been obtained using the variable permeability model which qualitatively simulated the effects occurring if there is significant water plugging in the lower chimney regions. Similar results could be obtained during the pressurization phase of the test assuming there existed a flow channel. However, the decay portion of the pressure history curve (see Figure 7) cannot be reproduced using this model. Furthermore, to reproduce the interface re-entry drift probe hole data it is necessary to assume the flow channel is not in the vicinity of this hole.

Results of the calculations described in the preceding paragraphs are not intended to provide a detailed description of the relative gas permeabilities and porosities within the chimney. They are meant to show that the observed pressure histories can not be modeled by procedures satisfactory for other chimneys. Reasonable descriptions could be developed assuming the existence of a flow channel, or water flow in the lower chimney region.

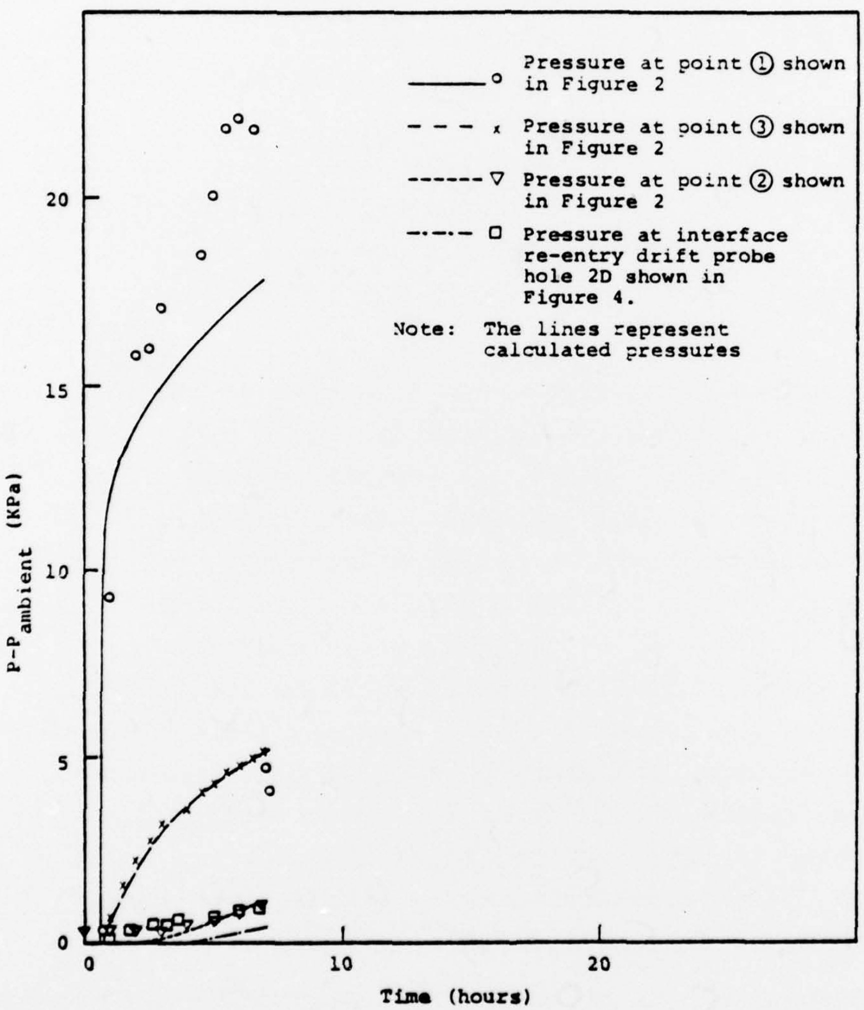


Figure 11. Comparison of measured pressures with calculated values obtained using values of relative gas porosity and permeability shown in Figure 12.

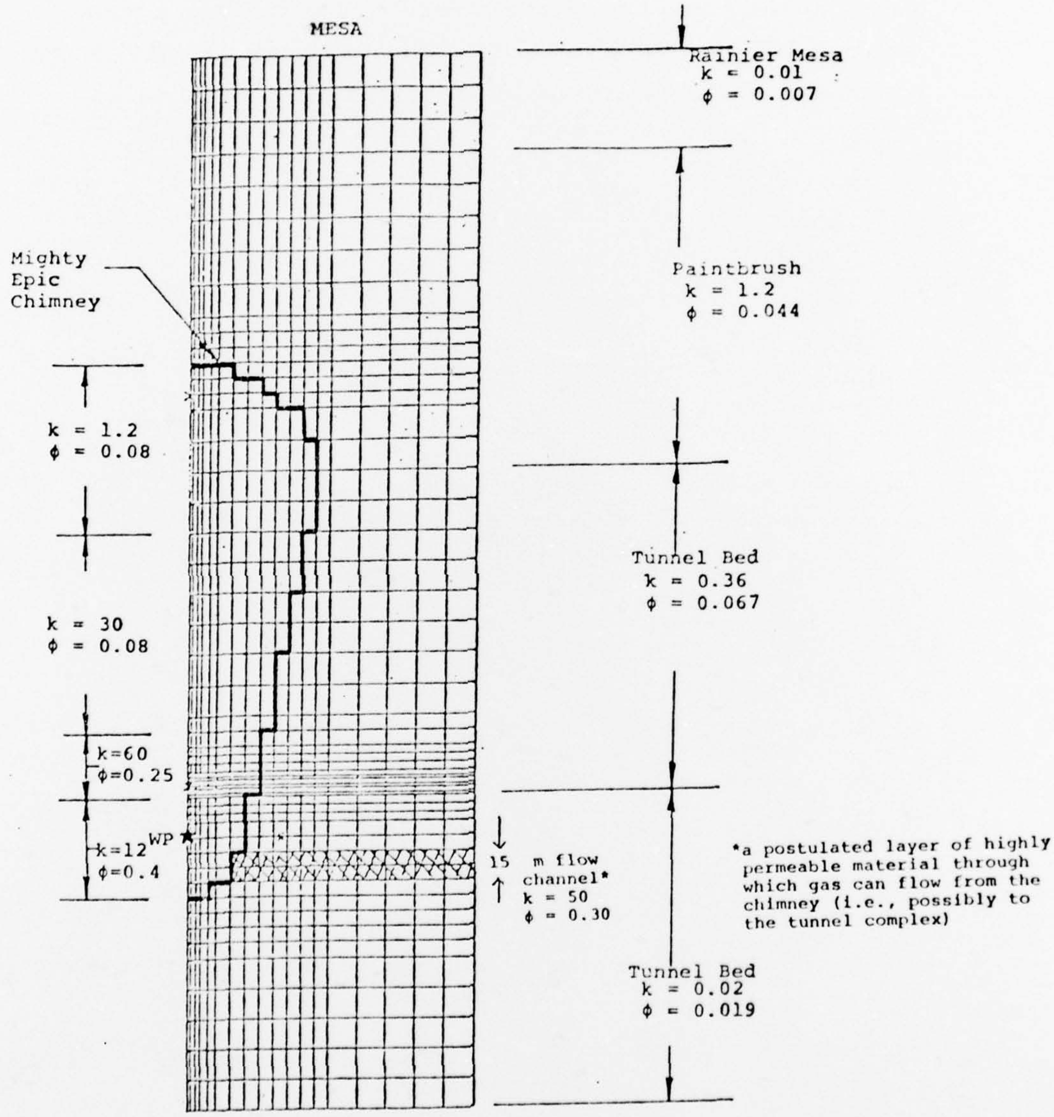


Figure 12. Calculational grid for Mighty Epic chimney showing distribution of material properties used to obtain the results shown in Figure 11.

The calculated results strongly indicate that water movement was responsible for variations in the pressure response observed during the two tests, and, for the somewhat unusual pressure response observed during the first test.

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1. Peterson, E., et al, "Gas Flow Calculations for the Ming Blade Chimney - Preliminary Calculational Results," Systems, Science and Software Report SSS-R-76-2170, November 1975.

2. Peterson, E., et al, "Summary of the Dining Car Tracer Gas Chimney-Pressurization Studies," Systems, Science and Software Report SSS-R-77-3185, April 1977.

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APPENDIX I

During the first Mighty Epic test air samples taken at the U12n.10 DNEX#1 hole leading to the Mighty Epic WP and at the interface re-entry drift probe hole showed evidence of the injected Freon C318 tracer. In addition, evidence of this tracer was found in air samples taken at various places within the tunnel complex. The tracer gas concentration histories for these locations are shown in Figure I-1 and I-2.

The tracer gas concentration histories at the working point, the interface probe hole, and the S^3 instrumentation station located at the intersection of the Mighty Epic interface re-entry and by-pass drifts are shown in Figure I-1. Concentrations at the WP and probe hole are seen to increase with time as anticipated. The background tracer gas level at the instrumentation station is seen to be negligible. Figure I-2 shows the concentration in the Ming Blade re-entry drift, at the Diablo Hawk working point and at the Mighty Epic DAC. These concentrations are seen to increase with time while the concentration at the S^3 instrumentation position remains negligible. It should be noted that any Freon C318 entering the tunnel complex from the injection region must first flow past the S^3 instrumentation station. To date it has proved impossible to determine the source of the Freon C318 found in the tunnel complex during the first Mighty Epic test.

During the morning of 14 November 1976 additional gas samples were taken throughout the entire N tunnel complex. Freon C318 was observed at all locations sampled. The tracer gas was thought to have been distributed throughout the tunnel complex as a result of train traffic. Subsequent checks with smoke indicate the train acts as a giant plunger continually moving and mixing the air within the tunnel. In addition, some air is probably caught in the man-cars and transported toward the portal.

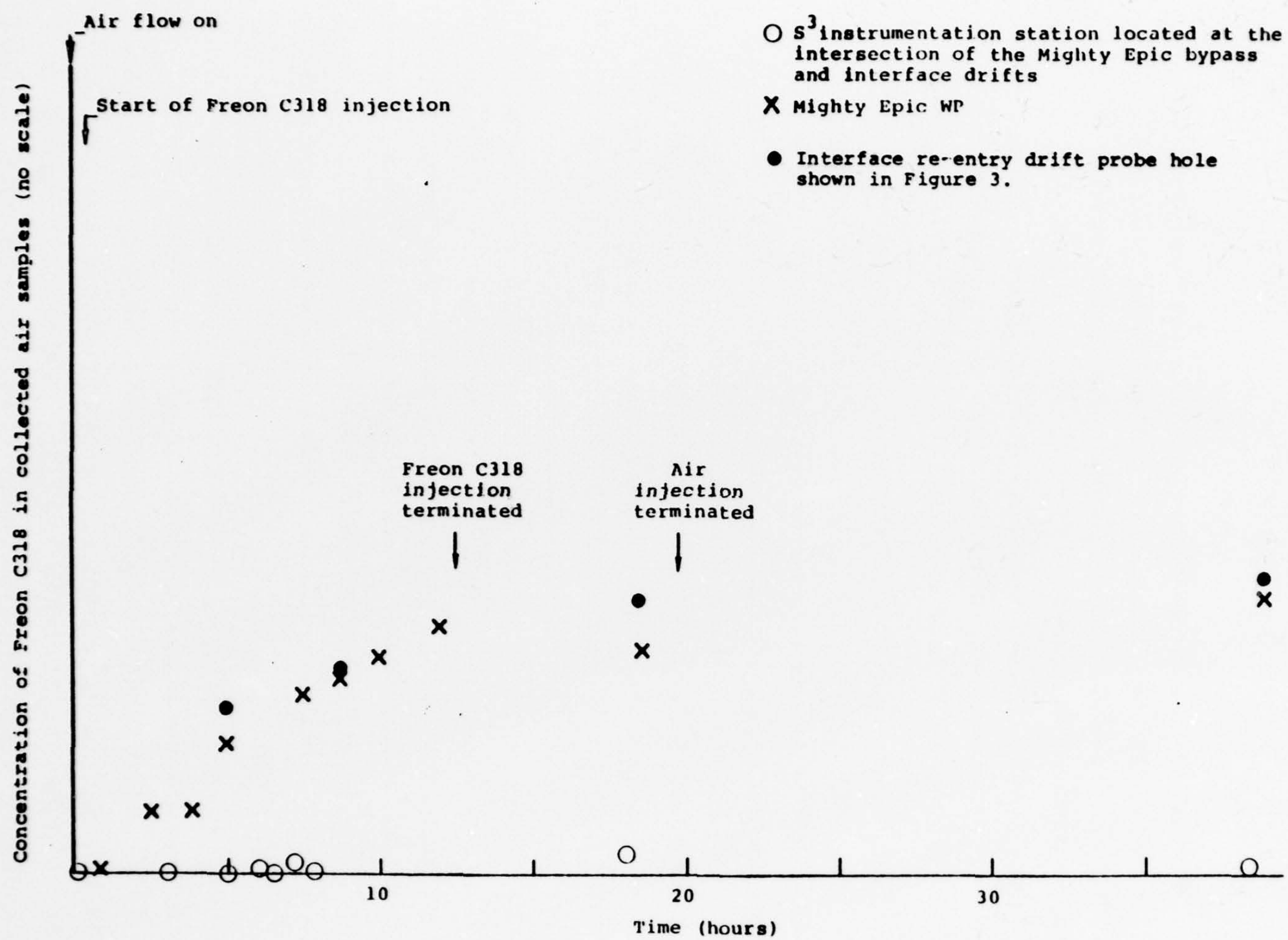

Figure I-1. History of Freon C318 concentrations measured during the 12 November 1976 Mighty Epic chimney pressurization test.

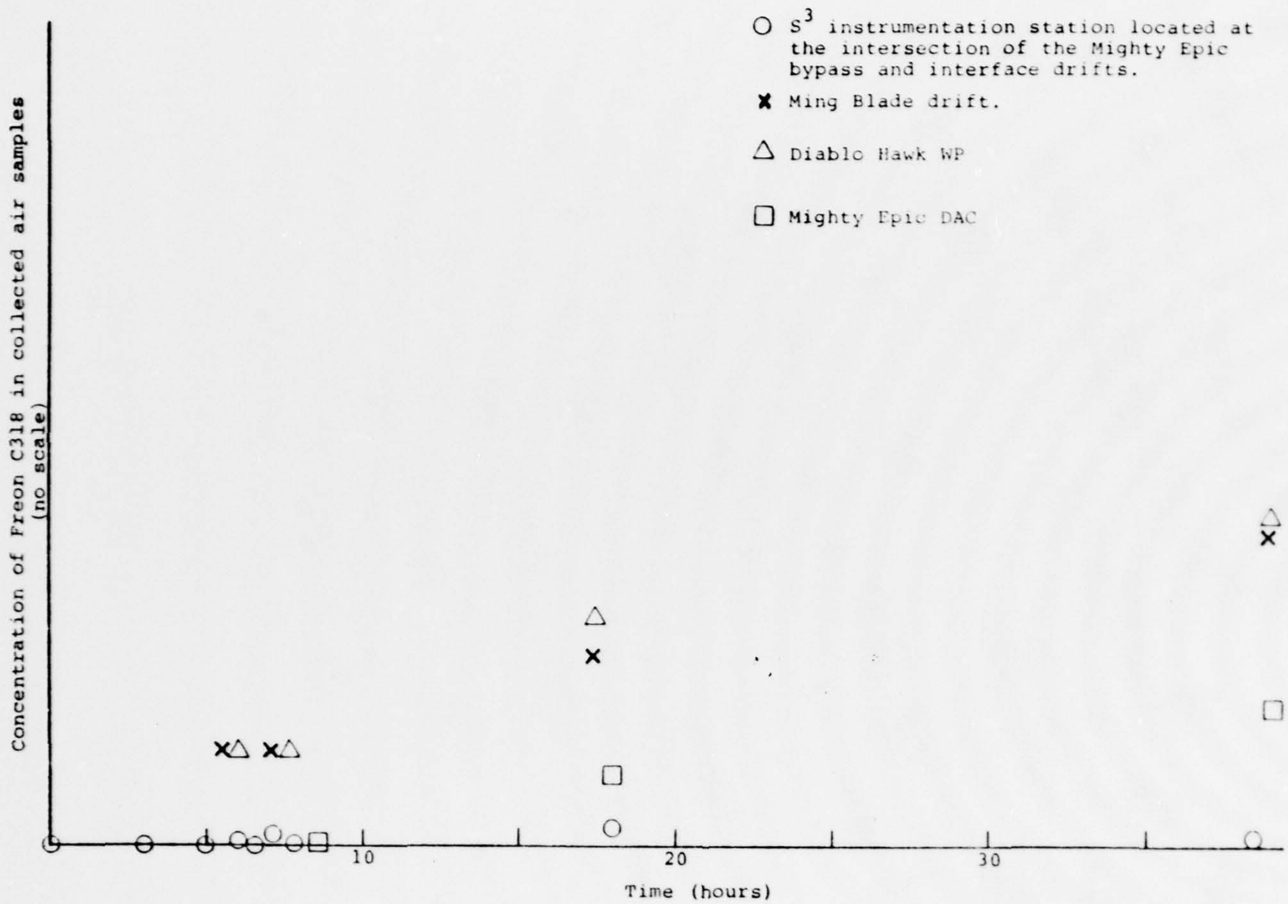

Figure I-2. History of Freon C318 concentrations measured in the tunnel complex during the 12 November 1976 Mighty Epic chimney pressurization test.

Multiple train trips can therefore easily spread measurable quantities of tracer gas throughout the tunnel complex. Recall that Freon C318 can be detected at concentrations of 10^{-10}. As a result, the train traffic was halted and the ventilation system shut down during the second Mighty Epic test.

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